VERIFICATION

The undersigned, of the below address, hereby certifies that he/she well knows both the English and Japanese languages, and that the attached is an accurate English translation of the Japanese Patent application filed on March 27, 2003 under No. P2003-087894.

The undersigned declares further that all statements made herein of his/her own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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JAPAN PATENT OFFICE

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Date of Application: March 27,2003

Application Number: Japanese Patent Application No.2003-087894

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Commissioner,

Patent Office (Seal)

(Document Name)Patent Application

(Reference Number) 2003-0020

(Presentation Date) March 27 , 2003

(Directly) Commissioner of the Patent Office

(IPC) H01L 31/09

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(Official Fee)

(Pre-Paid Master Note Number) 014708

(Amount to be paid) 21000 yen

(Lists of the Article to be presented)

(Name of Article) Specification 1

(Name of Article) Drawing 1

(Name of Article) Abstract 1

(Proof Reading) Required

[Document Title] Specification

[Title of the Invention] PHOTODIODE ARRAY, PRODUCTION METHOD THEREOF, AND RADIATION DETECTOR

[Scope of Claims]

[Claim 1] A photodiode array, comprising:

a semiconductor substrate on which a plurality of photodiodes are formed in an array on an opposite surface side to an incident surface of light to be detected,

wherein, on the incident surface side, a resin film for transmitting the light to be detected is provided so as to covers at least a region corresponding to a region where the photodiodes are formed.

[Claim 2] The photodiode array according to claim 1,

wherein the semiconductor substrate has front surface side depression portions, which are recessed more than surrounding regions, on the opposite surface side to the incident surface, and the photodiodes are formed at a bottom portion of the front surface side depression portions.

[Claim 3] The photodiode array according to claim 1 or 2,

wherein the resin film is provided on the entire incident surface.

[Claim 4] The photodiode array according to any of claims 1 to 3,

wherein the semiconductor substrate is provided with an impurity region between the photodiodes adjacent to each

other, for separating the photodiodes from each other.

[Claim 5] The photodiode array according to any of claims 1 to 4,

wherein a high-impurity-concentration layer of the same conductivity type as the semiconductor substrate is formed on the incident surface side of the semiconductor substrate.

[Claim 6] A method of producing a photodiode array, the method comprising:

a first step of adding impurities to form a plurality of second conductivity type impurity diffused layers on one surface side of a semiconductor substrate constituted by a semiconductor of a first conductivity type, and forming a plurality of photodiodes arranged in an array using the impurity diffused layers and the semiconductor substrate; and

a second step of providing, on an opposite surface side to a side on which the impurity diffused layers are formed, a resin film for transmitting light to which the photodiodes are sensitive, so as to covers at least a region corresponding to a region where the photodiodes are formed.

[Claim 7] A method of producing a photodiode array, the method comprising:

a first step of forming a plurality of front surface side depression portions, which are recessed more than surrounding regions, arranged in an array on one surface side of a semiconductor substrate constituted by a semiconductor

of a first conductivity type;

a second step of adding impurities to bottom portions of the front surface side depression portions to form a plurality of second conductivity type impurity diffused layers and forming a plurality of photodiodes arranged in an array using the impurity diffused layers and the semiconductor substrate; and

a third step of providing, on an opposite surface side to a side on which the impurity diffused layers are formed, a resin film for transmitting light to which the photodiodes are sensitive, so as to covers at least a region corresponding to a region where the photodiodes are formed.

[Claim 8] The method of producing a photodiode array according to claim 6 or 7, further comprising:

a step of forming a high-impurity-concentration layer of the same conductivity type as the semiconductor substrate on the opposite surface side, prior to providing the resin film.

[Claim 9] The method of producing a photodiode array according to any of claims 6 to 8, further comprising:

a step of providing a first conductivity type impurity region by adding, between adjacent regions to which the impurity is added, a different impurity.

[Claim 10] A radiation detector, comprising:

the photodiode array according to any of claims 1 to 5; and

a scintillator panel, which is attached to an incident

surface side of the light to be detected on the photodiode array, and emits light due to incidence of radiation.

[Claim 11] A radiation detector, comprising:

a photodiode array produced by the production method according to any of claims 6 to 9; and

a scintillator panel, which is attached to a side of the photodiode array at which the resin film is provided, and emits light due to incidence of radiation.

[Detailed Description of the Invention]

[0001] [Field of the Invention]

The present invention relates to a photodiode array, a production method thereof, and a radiation detector.

[0002] [Prior Art]

Photodiode arrays of this type conventionally known include back-illuminated photodiode arrays of a type in which light is incident from an opposite side (back side) of a surface where bump electrodes or the like are formed (see Patent Document 1 for example). As shown in Figs. 25 and 26, the photodiode array disclosed in Patent Document 1 has photodiodes 140 of pn junctions made by forming columnar p-layers 134 on an n-type silicon substrate 133, and a scintillator 131 is bonded through a negative electrode film 136 to the back surface (upper side in the drawing) opposite to the front surface (lower side in the drawing) where the photodiodes 140 are formed. When light resulting from wavelength conversion in the scintillator 131 is incident into the photodiodes 140, each of the photodiodes 140 generates an electric current according to the incident light, and these electric currents are connected to solder pads 138, which are provided on a printed circuit board 137, through positive electrodes 135 on the front surface side and solder balls 139.

[0003] Patent Document 1

Japanese Patent Application Laid-Open No. 7-333348

[0004] [Problems to be Solved by the Invention]

In this regard, when mounting the aforementioned photodiode array, a photodiode array for CT for example, a flat collet or a pyramid collet can be used as a collet for suction-clamping a chip, but a flat collet is normally used for flip chip bonding. CT photodiode arrays have a large chip area (for example, a rectangular shape with a 20 mm side) and, as shown in Fig. 24(b), when using a pyramid collet 161 that is used in an ordinary mounter, warping may occur due to a clearance 163 between a chip 162 and the pyramid collet 161, and positional misalignment may occur due to this warping such that there is a risk of mounting accuracy being reduced. Furthermore, flip chip bonding requires the application of heat and pressure, but in addition to the poor thermal conduction efficiency of the pyramid collet 161, it may cause damage to the edges of the chip due to the pressure that is applied, and therefore the pyramid collet 161 is unsuitable for thin chips. For such reasons, when carrying out flip chip bonding, while the chip 162 is suction-clamped by a flat collet 160 that surface-contacts the chip surface as shown in Fig. 24(a), heat and pressure are applied from a heater block 164 to the chip 162.

[0005] However, when using the flat collet 160, the entire chip surface of the chip 162 is brought into contact with the flat collet 160. If the entire chip surface, which will become the light-incident surface, is brought into contact with the flat collet 160 and subjected to pressure and heat,

regions on the chip surface corresponding to impurity diffused layers that constitute the photodiodes will suffer physical damage and therefore the defective appearance and degradation in characteristics (increases in dark current and noise or the like) caused by this damage will adversely affect the photodiode array.

[0006] Accordingly, an object of the present invention is to solve the above-described problems and to provide a photodiode array, a production method thereof, and a radiation detector capable of preventing the degradation in characteristics occurring during mounting due to the damage that adversely affects regions corresponding to regions in which the photodiodes are formed.

[0007] [Means for Resolving the Problems]

In order to resolve the above-described problems, a photodiode array according to the present invention is provided with a semiconductor substrate on which a plurality of photodiodes are formed in an array on an opposite surface side to an incident surface of light to be detected, wherein, on the incident surface side, a resin film for transmitting the light to be detected is provided so as to covers at least a region corresponding to a region where the photodiodes are formed.

With this photodiode array, since the resin film is interposed between the corresponding regions of the photodiodes and the flat collet that is used at the time of

mounting, the corresponding regions do not make direct contact with the flat collet and are protected such that damage due to pressure or heat is not incurred.

[0008] Furthermore, in the above-described photodiode array, it is possible that the semiconductor substrate has front surface side depression portions, which are recessed more than surrounding regions, on the opposite surface side to the incident surface, and the photodiodes are formed at a bottom portion of the front surface side depression portions.

With these photodiodes, since the distance from the incident surface of the light to be detected of the semiconductor substrate to the photodiodes is reduced, recombination during the migration process of carriers produced by incidence of light to be detected is suppressed.

[0009]

Furthermore, with the above-described photodiodes, the resin film may be provided on the entire incident surface. In this case, the production process can be simplified.

Further still, in the aforementioned photodiode array, it is possible that the semiconductor substrate is provided with an impurity region (separating layer) between the photodiodes adjacent to each other, for separating the photodiodes from each other. In these photodiode arrays, surface leaking is suppressed by the separating layer, and therefore adjacent photodiodes are reliably electrically separated from each other.

In any of the aforementioned photodiodes, it is preferable that a high-impurity-concentration layer of the same conductivity type as the semiconductor substrate is formed on the incident surface side of the semiconductor substrate. In such a photodiode array, carriers produced near the light-incident surface inside the semiconductor substrate migrate efficiently to the photodiodes without being trapped, thereby making it possible to increase photodetecting sensitivity.

[0010] Also, the present invention provides a method of producing a photodiode array comprising, a first step of adding impurities to form a plurality of second conductivity type impurity diffused layers on one surface side of a semiconductor substrate constituted by a semiconductor of a first conductivity type, and forming a plurality of photodiodes arranged in an array using the impurity diffused layers and the semiconductor substrate, and a second step of providing, on an opposite surface side to a side on which the impurity diffused layers are formed, a resin film for transmitting light to which the photodiodes are sensitive, so as to covers at least a region corresponding to a region where the photodiodes are formed.

[0011] With this method of producing a photodiode array, a photodiode array is obtained in which the photodiodes are formed arranged in an array on one surface side of the semiconductor substrate, and, on the opposite surface side

thereof, a resin film for transmitting the light to be detected by the photodiodes is provided so as to covers at least a region corresponding to a region where the photodiodes are formed.

Also, the present invention provides a method of producing a photodiode array comprising a first step of forming a plurality of front surface side depression portions, which are recessed more than surrounding regions, arranged in an array on one surface side of a semiconductor substrate constituted by a semiconductor of a first conductivity type, a second step of adding impurities to bottom portions of the front surface side depression portions to form a plurality of second conductivity type impurity diffused layers and forming a plurality of photodiodes arranged in an array using the impurity diffused layers and the semiconductor substrate, and a third step of providing, on an opposite surface side to a side on which the impurity diffused layers are formed, a resin film for transmitting light to which the photodiodes are sensitive, so as to covers at least a region corresponding to a region where the photodiodes are formed.

[0012] With this production method, a photodiode array is obtained in which the front surface side depression portions are formed on the front surface on one side of the semiconductor substrate and the photodiodes are formed arranged in an array in bottom portions of those front surface side depression portions and, on the opposite side thereof, a

resin film for transmitting the light to be detected by the photodiodes is provided so as to covers at least a region corresponding to a region where the photodiodes are formed.

Any of the aforementioned methods of producing a photodiode array may comprise a step of forming a high-impurity-concentration layer of the same conductivity type as the semiconductor substrate on the opposite surface side, prior to providing the resin film. With such a production method, by forming the high-impurity-concentration layer with the same conductivity type as the semiconductor substrate, a photodiode array can be obtained in which the carriers produced near the light-incident surface inside the semiconductor substrate migrate efficiently to the photodiodes without being trapped, thereby improving the photodetecting sensitivity.

[0013] Furthermore, any of the aforementioned methods of producing a photodiode array may further comprise a step of providing a first conductivity type impurity region by adding, between adjacent regions to which the impurity is added, a different impurity. With such a production method, a photodiode array is obtained in which adjacent photodiodes are reliably electrically separated.

Also, the present invention provides a radiation detector comprising any of the aforementioned photodiode arrays, and a scintillator panel, which is attached to an incident surface side of the light to be detected on the

photodiode array, and emits light due to incidence of radiation.

[0014] Furthermore, the present invention provides a radiation detector comprising a photodiode array produced by any of the aforementioned production methods, and a scintillator panel, which is attached to a side of the photodiode array at which the resin film is provided, and emits light due to incidence of radiation.

Since these radiation detectors are provided with the aforementioned photodiode array, the corresponding regions of the photodiodes are protected by the resin film and do not suffer damage due to pressure or heat during mounting such that degradation in characteristics due to noise and dark current or the like can be prevented.

[0015] [Embodiments of the Invention]

Hereinafter, embodiments of the present invention are described. It should be noted that identical numerical symbols are used for identical elements and duplicated description is omitted.

(First Embodiment)

First, an embodiment of a photodiode array and a production method thereof are described.

Fig. 1 is a cross sectional view that schematically shows a photodiode array 1 according to an embodiment of the present invention. It should be noted that in the following description, an incident surface (upper side in Fig.

1) of light L is a back surface and a surface of an opposite side thereof (lower side in Fig. 1) is a front surface. In the following drawings, dimensions are altered as required for convenience of illustration.

[0016] On a front surface side, the photodiode array 1 has a plurality of photodiodes 4, which are constituted by pn junctions, arranged two-dimensionally in a vertically and horizontally regular array, and each of these photodiodes 4 functions as a pixel of the photodiode array 1 such that as a whole they constitute a single photodetecting portion.

The photodiode array 1 has a thickness of approximately 30 to 300 μm (preferably 100 μm) and has an n-type (first conductivity type) silicon substrate 3 having an impurity concentration of approximately 1×10^{12} to $10^{15}/cm^3$. On a front surface side thereof, p-type (second conductivity type) impurity diffused layers 5, which have an impurity concentration of approximately 1×10^{13} to $10^{20}/cm^3$ and a film thickness of approximately 0.05 to 20 μm (preferably 0.2 μm), are arranged two-dimensionally in a vertically and horizontally regular array. The pn junctions formed by the p-type impurity diffused layers 5 and the n-type silicon substrate 3 constitute the photodiodes 4. Further still, a silicon oxide film 22 is formed on the front surface side and formed on this is a passivation film 2.

[0017] Furthermore, electrode wirings 9 are formed for each of the photodiodes 4. The electrode wirings 9 are made

of aluminum of a thickness of approximately 1 μm and are electrically connected to the p-type impurity diffused layers at the front surface side. Furthermore, bump electrodes 12 of solder are electrically connected to the electrode wirings 9 through under bump metal (UBM) 11 made of Ni-Au at areas where the passivation film 2 is opened at predetermined positions.

[0018] On the other hand, an accumulation layer 8, which is a high-impurity-concentration layer, is provided on the back surface side of the n-type silicon substrate 3. The accumulation layer 8 is formed having a substantially uniform depth across almost all the back surface side and is the same conductivity type as the n-type silicon substrate 3, while having a higher impurity concentration than that of the n-type silicon substrate 3. Furthermore, an AR film 24 is formed that covers and protects the accumulation layer 8 and suppresses reflection of the light L. The AR film 24 is made of SiO_2 and is formed having a thickness of approximately 0.01 to several μm. It should be noted that, although provided with the accumulation layer 8, the photodiode array 1 has a photodetecting sensitivity of sufficient tolerance in practical use even when the accumulation layer 8 is not provided. It should also be noted that instead of SiO_2, the AR film 24 may be formed of SiN or a multilayer or complex structure of an optical film capable of preventing reflection at a required wavelength.

[0019] Regions in which the p-type impurity diffused layers 5 of the front surface side are present are regions (formed regions) where the photodiodes 4 are formed, and regions other than these are non-formed regions where photodiodes are not formed. The transparent resin film 6, which is capable of covering at least all the regions (hereinafter referred to as "corresponding regions") that correspond to the formed regions of the photodiodes 4, is provided over all the back surface side AR film 24.

[0020] Further still, the photodiode array 1 shown in the diagram is provided with an n^+-type impurity region (separating layer) 7 of a film thickness of approximately 0.1 μm to several tens of μm between the p-type impurity diffused layers 5, that is, between the adjacent photodiodes 4. The n^+-type impurity regions (separating layers) 7 have a function of electrically separating adjacent photodiodes 4 from each other, and by providing these it is possible to reliably electrically separate adjacent photodiodes 4 from each other and reduce crosstalk between photodiodes 4. However, the photodiode array 1 has photodetecting characteristics to achieve sufficient tolerance in practical use even when the n^+-type impurity regions 7 are not provided.

[0021] Fig. 2 includes a lateral view of a semiconductor chip 30 that constitutes the photodiode array 1 and a cross sectional view magnifying principal portions thereof. As shown in Fig. 2, the semiconductor chip 30 is a chip having a

width W1 of approximately 22.4 mm, is of an extremely thin board shape having a thickness D of approximately 0.3 mm, has a multitude of the aforementioned photodiodes 4 (a two-dimensional array of 16 × 16 diodes for example), and has a large surface area (22.4 mm × 22.4 mm for example) in which a pitch W2 between adjacent pixels is approximately 1.4 mm.

[0022] With the photodiode array 1 that is structured as described above, when the light L is incident from the back surface side where the photodiodes 4 are not formed, the light L to be detected passes through the transparent resin film 6 and an accumulation layer 8 to reach the pn junctions, and the photodiodes 4 generate carriers corresponding to that incident light. At this time, the accumulation layer 8 functions to suppress trapping of the carriers at the interface with the light-incident surface and the AR film 24, these carriers being generated by the incident light L near the light-incident surface (back surface) inside the n-type silicon substrate 3, and such that the carriers are efficiently moved to the pn junctions to increase the photodetecting sensitivity of the photodiode array 1. Then, the photocurrents generated by the carriers are extracted from the bump electrodes 12 via the electrode wirings 9 and the UBMs 11 connected to the p-type impurity diffused layers 5. Detection of incident light is carried out based on the output from the bump electrodes 12.

[0023] As described above, with the photodiode array 1,

the transparent resin film 6, which is capable of covering all the corresponding regions of the photodiodes 4, is provided on the incident surface side. When the semiconductor chip 30 is suction-clamped to a flat collet to carry out flip chip bonding, the transparent resin film 6 comes in contact with the flat collet and is arranged in a form interposed between the flat collet and the corresponding regions of the photodiodes 4. Thus, the corresponding regions of the photodiodes 4, which constitute the photodetecting portion, are protected by the transparent resin film 6 and do not come into direct contact with the flat collet. Accordingly, the corresponding regions of the photodiode array 1 are not directly subjected to stress caused by pressure or stress caused by heat, and therefore the accumulation layer 8 of the corresponding regions does not suffer physical damage and in the photodiodes 4 there is no occurrence of dark current or noise originating in crystal defects or the like caused by such damage. Thus, the photodiode array 1 is able to perform photodetection with high accuracy (at high S/N ratios).

[0024] Furthermore, as will be described later, the transparent resin film 6 is capable of achieving a function as a cushion layer capable of protecting the corresponding regions of the photodiodes 4, and therefore is also capable of absorbing physical impact at the time of suction-clamping with the flat collet, and is also effective in this regard to this point.

Further still, in addition to flip chip bonding, in cases where the photodiode array 1 is integrated with a scintillator to be used as a CT sensor for example, the scintillator is not brought into direct contact with the corresponding regions, and therefore it is also possible to avoid damage that occurs when the scintillator is mounted.

[0025] In this regard, the transparent resin film 6 should be provided in a range capable of covering at least all the corresponding regions of the photodiodes 4. As long as this condition is met, all the corresponding regions may be covered by a single transparent resin film 6, or the transparent resin film 6 may be formed separately for each of the corresponding regions of the photodiodes 4 and missing portions 6a, which are partially unformed, may be formed in regions (hereinafter referred to as "non-corresponding regions") not corresponding to the formed regions of the photodiodes 4 (see Fig. 12). However, in regard to the point of simplifying the production process, it is preferable that the resin film is provided on the entire back surface side (this point will be described later).

[0026] Also, since the transparent resin film 6 acts as a protective film for all the corresponding regions of the photodiodes 4 and is arranged on the incident surface side, the transparent resin film 6 is made of a light transmitting resin that is capable of transmitting light detected by the photodiode array 4 (light to be detected, e.g., fluorescence

generated by scintillator panel 31 as described later) and optically transparent to the light to be detected; for example, an epoxy resin and such resins as polyimide, acrylate, silicone, fluorine, or urethane. Furthermore, since the transparent resin film 6 is a component that is brought into direct contact with the flat collet and subjected to pressure and heat when flip chip bonding is performed, it is preferable that the transparent resin film 6 is prepared having a characteristic of being capable of functioning as a cushion layer that protects the corresponding regions of the photodiodes 4 from such pressure and heat. In this case, it is preferable that it has, for example, a coefficient of thermal expansion of approximately 1×10^{-6} to 1×10^{-4}/°C, an elastic characteristic of a elastic modulus of approximately 10 to 12,000 kg/cm^2, with thermal conductivity of 0.2 to 1.85 W/m°C, and a film thickness (approximately 1 to 50 μm (preferably 10 μm)) capable of absorbing light from at least the scintillator panel 31, which will be described later, without ions of impurities diffusing into the photodiodes 4 due to heat.

[0027] Next, a production method for the photodiode array 1 according to the present embodiment is described with reference to Figs. 3 to 11.

First, as shown in Fig. 3, the n-type silicon substrate 3 is prepared having a thickness of approximately 150 to 500 μm (preferably 350 μm), and thermal oxidation is carried out to form (see Fig. 4) a silicon oxide film (SiO_2) 20 on the front

surface and back surface of the n-type silicon substrate 3.

[0028] Next, patterning is carried out on the silicon oxide film 20 of the front surface side of the n-type silicon substrate 3 using a predetermined photomask such that only regions in which the n^+-type impurity regions 7 are intended to be provided are opened, and phosphorus doping is carried out through these areas that have been opened (open portions) to provide the n^+-type impurity regions 7. In the present embodiment, the n^+-type impurity regions 7 are also formed on the back surface side, but in cases where the n^+-type impurity regions 7 are not provided on either the front surface side or the back surface side, this step (impurity region forming step) may be omitted. Subsequently, a silicon oxide film 21 is again formed on the front surface and back surface of the substrate (see Fig. 5). The silicon oxide film 21 is used as a mask in the subsequent step of forming the p-type impurity diffused layers 5.

[0029] Following this, patterning is carried out on the silicon oxide film 21 of the front surface side using a predetermined photomask such that only regions in which the p-type impurity diffused layers 5 are intended to be formed are opened. Then, boron doping is carried out through the open portions such that the p-type impurity diffused layers 5 form a two-dimensional arrangement in a vertical-horizontal array shape. Thus, the photodiodes 4 that are made of pn junctions of the p-type impurity diffused layers 5 and the

n-type silicon substrate 3 are formed on the front surface side in a two-dimensional arrangement in a vertical-horizontal array shape such that the photodiodes 4 become portions corresponding to pixels. Subsequently, thermal oxidation is carried out to again form a silicon oxide film 22 on the front surface side of the substrate (see Fig. 6).

[0030] Next, the back surface is polished until an overall thickness of the n-type silicon substrate 3 becomes a predetermined thickness (approximately 30 to 300 μm) to change the n-type silicon substrate 3 into a thin shape (thin board), and an n-type ion species (for example, phosphorus or arsenic) is allowed to diffuse into the back surface side to a depth of approximately 0.05 to several ten μm, thereby forming the aforementioned accumulation layer 8 with an impurity concentration higher than that of the n-type silicon substrate 3. Further still, a buffer oxide film 23 is removed from the back surface side while the front surface side is in a protected state and thermal oxidation is again carried out to form the AR film 24 on the back surface side (see Fig. 7).

[0031] Then, using a photoetching technique in the formed regions of the photodiodes 4, contact holes that connect to the p-type impurity diffused layers 5 are formed in the silicon oxide film 22. Following this, patterning is carried out using a predetermined photomask on the overall front surface side where an aluminum metal film has been formed by vapor deposition, and extraneous portions of the

metal film are removed to form the electrode wirings 9 (see Fig. 8).

Next, an epoxy resin, or a resin such as polyimide, acrylate, silicone, fluorine, or urethane is applied to the back surface side of the n-type silicon substrate 3 as a material to constitute the transparent resin film 6, and this is made to spread and harden over the entirety thereof by spin coating or a screen printing technique or the like, thereby providing the transparent resin film 6 (see Fig. 9). By providing the transparent resin film 6, the corresponding regions of the photodiodes 4, which constitute the photodetecting portion, are protected. It should be noted that when forming the above-mentioned missing portions 6a in the transparent resin film 6, the applied resin may be removed from areas of the missing portions 6a, but even so the corresponding regions of the photodiodes 4 will be protected. Then, after the transparent resin film 6 is formed as described above, the SiN 25 that is to become the passivation film 2 is formed on the front surface side using sputtering, plasma CVD or the like. The passivation film 2 may be an insulating film such as SiO_2, PSG, or BPSG, a polyimide, acyrlate, epoxy or fluorocarbon resin, or a composite film or multilayer film or the like of any of these. It should be noted that the step of forming the passivation 2 may be performed before forming a transparent resin film 6.

[0032] Following this, contact holes are formed at

predetermined positions in the SiN 25 to make electrode extraction portions (see Fig. 10). Further still, although the bump electrodes 12 are provided, when using solder as the bump electrodes 12, since solder has poor wettability to aluminum, the UBMs 11 for intervening between the electrode extraction portions and the bump electrodes 12 are formed at the electrode extraction portions, then the bump electrodes 12 are formed over the UBMs 11 (see Fig. 11). Through the above steps, the photodiode array 1 can be produced capable of performing photodetection with high accuracy, without any occurrence of noise due to damage in mounting.

[0033] Here, the UBMs 11 are formed as Ni-Au using electroless plating, but they may also be formed as a material such as Ti-Pt-Au or Cr-Au using a lift-off technique. Furthermore, the bump electrodes 12 can be achieved by forming solder on the predetermined UBMs 11 using a solder ball mounting technique or a printing technique and then reflowing the solder. It should be noted that the bump electrodes 12 are not limited to solder, but may be gold bumps, nickel bumps, or copper bumps, or may be conductive resin bumps containing a metal such as a conductive filler. It should be noted that the drawings show only the extraction of the anode electrodes, but the cathode (substrate) electrodes (though not shown) can also be extracted from the n^+-type impurity regions 7 in the same manner as the anode electrodes. Furthermore, the drawings show a case in where the bump

electrodes 12 of the anode electrodes are formed in the areas of the n^+-type impurity regions 7, but the bump electrodes 12 of the anode electrodes may be formed in the areas of the p-type impurity diffused layers 5.

[0034] Next, a first embodiment of a radiation detector according to the present invention is described.

Fig. 22 is a sectional side view of a radiation detector 50 according to the present embodiment. The radiation detector 50 is provided with a scintillator panel 31 that emits light, which is produced by radiation when radiation is incident, from a light exit surface 31a and the above-described photodiode array 1 that receives the light emitted from the scintillator panel 31 at a light-incident surface and converts it to an electrical signal. The radiation detector 50 is characterized in being provided with the photodiode array 1 according to the present invention.

[0035] The scintillator panel 31 is attached on the back surface side (incident surface side) of the photodiode array 1, but the photodiode array 1 is provided with the above-mentioned transparent resin film 6 on its back surface side. Thus, the back surface of the scintillator panel 31, that is, the light exit surface 31a, does not directly contact the corresponding regions of the photodiodes 4. Furthermore, the clearance between the light exit surface 31a of the scintillator panel 31 and the back surface side of the transparent resin film 6 is filled with an optical resin 35

having a refractive index whose characteristics give consideration to allowing light to permeate sufficiently and, due to the optical resin 35, the light emitted from the scintillator panel 31 is made incident on the photodiode array 1 with good efficiency. An epoxy resin, acrylic resin, urethane resin, silicone resin, fluorocarbon resin or the like having a property of allowing light emitted from the scintillator panel 31 to permeate can be used for the optical resin 35, or a composite material of these can be used.

[0036] Then, when bonding the photodiode array 1 onto a mounting wiring board, which is not shown in the drawings, the front surface is suction-clamped by the flat collet. However, since the above-described transparent resin film 6 is provided on the back surface of the photodiode array 1, the suction-clamping surface of the flat collet does not make direct contact with the corresponding regions, and when the scintillator panel 31 is mounted, the light exit surface 31a also does not make direct contact with the corresponding regions of the photodiodes 4. Accordingly, with the radiation detector 50 having the photodiode array 1 and the scintillator panel 31 it is possible to prevent occurrences of noise, dark current, and the like due to damage of the corresponding regions during mounting, and therefore photodetection can be carried out accurately and detection of radiation can also be performed accurately.

[0037] (Second Embodiment)

Next, a second embodiment of a photodiode array and a production method thereof are described.

The present embodiment is directed to a photodiode array 41 having an n-type silicon substrate 43 in which front surface side depression portions 45 are provided on the opposite surface side (front surface side) to the incident surface of the light L, as shown in Fig. 13. It should be noted that since this photodiode array 41 has common portions to the photodiode array 1, the description below is given with focus on the differences between them, while omitting or simplifying description of the common portions.

[0038] In the photodiode array 41, the front surface side depression portions 45 are formed in a two-dimensional arrangement of a vertically and horizontally regular array on the front surface side of the n-type silicon substrate 43. Each of the front surface side depression portions 45 is formed by recessing the substrate 43 so as to make it thinner than a region of a vicinity thereof, and formed such that there are arrangement intervals of approximately 1.4 to 1.5 mm. Then, one of the aforementioned photodiodes 4 is formed in each of respective bottom portions 45a thereof, thereby constituting the photodiode array 41 in which the photodiodes 4 are two-dimensionally arranged in an array.

[0039] On the front surface side, the front surface side depression portions 45 have a rectangular opening of a size of approximately 1 mm × 1 mm for example, and are formed by

recessing the substrate 43 so that the aperture size gradually decreases from the opening toward the bottom portion 45a (from the front surface side toward the back surface side), and the depth to the bottom portion 45a is approximately 50 μm for example. In this way, the front surface side depression portions 45 have a slope-shaped side surface 45b. Furthermore, at the front surface side for each of the photodiodes 4, the electrode wirings 9, which are electrically connected to the p-type impurity diffused layers 5, are formed along the side surfaces 45b. Openings are formed in the electrode wirings 9 at predetermined positions in the passivation film 2 in the same manner as the photodiode array 1 and, moreover, the bump electrodes 12 are electrically connected through the UBMs 11. Furthermore, an n^+-type impurity region 7 is provided between the adjacent photodiodes 4.

[0040] On the other hand, in the photodiode array 41, the accumulation layer 8 is formed on the entire back surface side and the AR film 24 is formed over this. The accumulation layer 8 and the AR film 24 are the same as for the above-described photodiode array 1. Then, the above-described transparent resin film 6 is provided on the entire AR film 24 including the corresponding regions of the photodiodes 4. The transparent resin film 6 is also the same as for the above-described photodiode array 1.

[0041] Fig. 14 includes a lateral view of a

semiconductor chip 36 that constitutes the photodiode array 41 and a cross sectional view magnifying principal portions thereof. As shown in Fig. 14, the semiconductor chip 36 is a chip having a width W1 of approximately 22.4 mm, is of an extremely thin board shape having a thickness D of approximately 150 to 300 μm, has a multitude of the aforementioned photodiodes 4 (a two-dimensional array of 16 × 16 diodes for example), and has a large surface area (22.4 mm × 22.4 mm for example) in which a pitch W2 between adjacent pixels is approximately 1.4 mm.

[0042] With the photodiode array 41 that is structured as described above, when the light L is incident from the back surface side where the photodiodes 4 are not formed, the light L to be detected passes through the transparent resin film 6 and the accumulation layer 8 to reach the pn junctions in the same manner as in the photodiode array 1, and the photodiodes 4 generate carriers in response to that light. At this time, since the p-type impurity diffused layers 5 are provided at the bottom portions 45a of the front surface side depression portions 45, a distance from the back surface of the n-type silicon substrate 43 to the photodiodes 4 is reduced (for example, to approximately 10 to 100 μm). Accordingly, the photodiode array 41 is configured to suppress circumstances by which the carriers, which are generated by the incident light L, terminate through recombination in the process of migration, and in this way, high detection

sensitivity can be maintained.

[0043] Furthermore, the accumulation layer 8 permits the carriers generated by incidence of the light L near the light-incident surface (back surface) inside the n-type silicon substrate 43 to efficiently migrate to the p-type impurity diffused layers 5 without recombination, thereby allowing the photodiode array 41 to have even higher photodetecting sensitivity (though the photodiode array 41 has detection sensitivity to achieve sufficient tolerance in practical use even when the accumulation layer 8 is not provided).

It should be noted that the photocurrents generated by the carriers are extracted from the bump electrodes 12 via the electrode wirings 9 and the UBMs 11 connected to the p-type impurity diffused layers 5. Detection of incident light is carried out based on the output from the bump electrodes 12. This point is the same as for the above-described photodiode array 1.

[0044] In the photodiode array 41, as with the photodiode array 1, the transparent resin film 6 is provided on the back surface side of the photodiodes 4, and therefore when the semiconductor chip 36 is suction-clamped to the flat collet to carry out flip chip bonding, the corresponding regions of the photodiodes 4 are protected by the transparent resin film 6 and do not make direct contact with the flat collet. Accordingly, the corresponding regions of the photodiode array 41 are not directly subjected to stress caused by

pressure or stress caused by heat, and therefore the accumulation layer 8 of the corresponding regions does not suffer physical damage and in the photodiodes 4 there is no occurrence of noise or dark current originating in such damage. Thus, the photodiode array 41 is able to perform photodetection with high accuracy (at high S/N ratios). Furthermore, in addition to flip chip bonding, in cases where the photodiode array 41 is integrated with a scintillator to be used as a CT sensor for example, the scintillator is not brought into direct contact with the corresponding regions, and therefore it is also possible to avoid damage that occurs when the scintillator is mounted.

[0045] Next, a production method for the photodiode array 1 according to the present embodiment is described with reference to Figs. 3 to 6 and Figs. 15 to 21. It should be noted that the hatching in portions of the drawings is omitted to facilitate illustration.

First, the steps in Figs. 3 to 6 are executed the same as for the photodiode array 1. Next, the back surface is polished until the thickness of the n-type silicon substrate 3 becomes a predetermined thickness to achieve a thin shape (thin board) with the n-type silicon substrate 3. Following this, a silicon nitride film (SiN) 26 is formed on the front surface and on the back surface of the n-type silicon substrate 3 by LP-CVD (or plasma CVD), then following this patterning is carried out on the silicon oxide film 22 and the silicon

nitride film 26 of the front surface side using a predetermined photomask to open only regions in which the front surface side depression portions 45 are intended to be formed (see Fig. 15).

[0046] Next, the front surface side depression portions 45 are formed on the front surface of the n-type silicon substrate 3 by performing alkali etching targeting regions in which the p-type impurity diffused layers 5 are formed so that frame peripheral portions 5a of the p-type impurity diffused layers 5 remain while an inner side thereof is removed, thereby obtaining the n-type silicon substrate 43. At this time, the frame peripheral portions 5a are formed in the openings of the front surface side depression portions 45 as regions in which p-type impurities are diffused, and following this the side surfaces 45b and the bottom portions 45b are formed. It should be noted that the frame peripheral portions 5a are not always essential, but by forming these an effect is obtained preventing dark current and noise that occurs due to damage at edge portions of depression portion etching of the front surface side depression portions 45. It should be noted that Figs. 13, 15, and 24 show examples in which there are no frame peripheral portions 5a in the photodiode array chip.

[0047] Following this, doping is carried out with boron or the like on the bottom portions 45b of the front surface side depression portions 45 that are formed. Thus, p-type impurity diffused layers 5b are formed at the bottom portions

45b of the front surface side depression portions 45 and the photodiodes 4 constituted by pn junctions of the p-type impurity diffused layers 5b and the n-type silicon substrate 43 on the front surface side are formed as a two-dimensional arrangement in a vertical-horizontal array shape. Further still, thermal oxidation is carried out and the silicon oxide film 22 is formed on portions not covered by the silicon nitride film 26 on the front surface side (see Fig. 16). It should be noted that at this time, although not shown in the drawings, a silicon oxide film is formed also on the silicon nitride film 26 on the back surface side.

[0048] Following this, once the silicon nitride film 26 has been removed from the back surface side while the front surface side is in a protected state, the aforementioned accumulation layer 8 having an impurity concentration higher than that of the n-type silicon substrate 43 is formed by ion implantation or the like at the back surface side with an n-type ion species (phosphorus or arsenic for example). Further still, thermal oxidation is carried out to form the AR film 24 on the back surface side. Thereafter, the silicon nitride film 26 is removed from the front surface side (see Fig. 17).

[0049] Then, using a photoetching technique in the formed regions of the photodiodes 4, contact holes that connect to the p-type impurity diffused layers 5b are formed in the silicon oxide film 22 of the front surface side.

Following this, patterning is carried out using a predetermined photomask on the overall front surface side where an aluminum metal film has been formed by vapor deposition, and extraneous portions of the metal film are removed using a photoetching technique to form the electrode wirings 9 (see Fig. 18). Next, the transparent resin film 6 is provided on the back surface side in the same manner as in the first embodiment (see Fig. 19).

[0050] Following this, the SiN 25 that is to become the passivation film 2 is formed on the front surface side using sputtering, plasma CVD or the like, and contact holes are formed at predetermined positions of the SiN 25. Following this, the SiN 25 is subjected to patterning so that only predetermined positions of the electrode wirings 9 are opened (see Fig. 20). Further still, in the same manner as in the first embodiment, the UBMs 11 that are to electrically connect to the wiring electrodes 9 of the openings and are made of Ni-Au are formed using electroless plating or the like, and by then forming the bump electrodes 12 on the UBMs 11 (see Fig. 21), it is possible to produce a photodiode array 41 capable of carrying out high-accuracy photodetection without occurrences of noise or dark current or the like due to damage incurred during mounting. It should be noted that the drawings show only the extraction of the anode electrodes, but the cathode (substrate) electrodes (though not shown) can also be extracted from the n^+-type impurity regions 7 in the

same manner as the anode electrodes.

[0051] Next, a second embodiment of a radiation detector according to the present invention is described.

Fig. 23 is a sectional side view of a radiation detector 55 according to the present embodiment. The radiation detector 55 is provided with a scintillator panel 31 that emits light, which is produced by radiation when radiation is incident, from a light exit surface 31a and the above-described photodiode array 41 that receives the light emitted from the scintillator panel 31 at a light-incident surface and converts it to an electrical signal. The radiation detector 55 is characterized in being provided with the photodiode array 41 according to the present invention.

[0052] The scintillator panel 31 is attached on the back surface side (incident surface side) of the photodiode array 41, but the photodiode array 41 is provided with the above-mentioned transparent resin film 6 on its back surface side. Thus, the back surface of the scintillator panel 31, that is, the light exit surface 31a, does not directly contact the corresponding regions of the photodiodes 4. Furthermore, the clearance between the light exit surface 31a of the scintillator panel 31 and the back surface side including the transparent resin film 6 is filled with the optical resin 35, which is the same as in the first embodiment, having a refractive index whose characteristics give consideration to allowing light to permeate sufficiently and, due to the optical

resin 35, the light emitted from the scintillator panel 31 is made incident on the photodiode array 41 with good efficiency.

[0053] Then, when bonding the photodiode array 41 onto a mounting wiring board, which is not shown in the drawings, the front surface is suction-clamped by the flat collet. However, since the above-described transparent resin film 6 is provided on the back surface of the photodiode array 41, the suction-clamping surface of the flat collet does not make direct contact with the corresponding regions, and when the scintillator panel 31 is mounted, the light exit surface 31a also does not make direct contact with the corresponding regions of the photodiodes 4. Accordingly, with the radiation detector 55 having the photodiode array 41 and the scintillator panel 31 it is possible to prevent occurrences of noise, dark current, and the like due to damage of the corresponding regions during mounting, and therefore photodetection can be carried out accurately and detection of radiation can also be performed accurately.

[0054] [Effects of the Invention]

With the present invention described above, in a photodiode array, a production method thereof, and a radiation detector, it is possible to effectively prevent occurrences of noise, dark current, and the like due to damage of the corresponding regions of photodiodes during mounting.

[Brief Description of the Drawings]

[Fig 1] Fig. 1 is a cross sectional view that schematically shows a magnification of principal portions of a photodiode array according to a first embodiment.

[Fig. 2] Fig. 2 includes a lateral view of a semiconductor chip that constitutes the photodiode array according to the first embodiment and a cross sectional view magnifying principal portions thereof.

[Fig. 3] Fig. 3 is a cross sectional view magnifying a principal portion of a photodiode array production process according to the first embodiment.

[Fig. 4] Fig. 4 is a cross sectional view magnifying principal portions of a process following that of Fig. 3.

[Fig. 5] Fig. 5 is a cross sectional view magnifying principal portions of a process following that of Fig. 4.

[Fig. 6] Fig. 6 is a cross sectional view magnifying principal portions of a process following that of Fig. 5.

[Fig. 7] Fig. 7 is a cross sectional view magnifying principal portions of a process following that of Fig. 6.

[Fig. 8] Fig. 8 is a cross sectional view magnifying principal portions of a process following that of Fig. 7.

[Fig. 9] Fig. 9 is a cross sectional view magnifying principal portions of a process following that of Fig. 8.

[Fig. 10] Fig. 10 is a cross sectional view magnifying principal portions of a process following that of Fig. 9.

[Fig. 11] Fig. 11 is a cross sectional view magnifying principal portions of a process following that of Fig. 10.

[Fig. 12] Fig. 12 is a cross sectional view that schematically shows a magnification of principal portions of a photodiode array having a transparent resin film with missing portions.

[Fig. 13] Fig. 13 is a cross sectional view that schematically shows a magnification of principal portions of a photodiode array according to a second embodiment.

[Fig. 14] Fig. 14 includes a lateral view of a semiconductor chip that constitutes the photodiode array according to the second embodiment and a cross sectional view magnifying principal portions thereof.

[Fig. 15] Fig. 15 is a cross sectional view magnifying principal portions in a midway step of a photodiode array production process according to the second embodiment.

[Fig. 16] Fig. 16 is a cross sectional view magnifying principal portions of a process following that of Fig. 15.

[Fig. 17] Fig. 17 is a cross sectional view magnifying principal portions of a process following that of Fig. 16.

[Fig. 18] Fig. 18 is a cross sectional view magnifying principal portions of a process following that of Fig. 17.

[Fig. 19] Fig. 19 is a cross sectional view magnifying principal portions of a process following that of Fig. 18.

[Fig. 20] Fig. 20 is a cross sectional view magnifying principal portions of a process following that of Fig. 19.

[Fig. 21] Fig. 21 is a cross sectional view magnifying principal portions of a process following that of Fig. 20.

[Fig. 22] Fig. 22 is a cross sectional view that schematically shows a magnification of principal portions of a radiation detector according to the first embodiment having a photodiode array according to the present invention.

[Fig. 23] Fig. 23 is a cross sectional view that schematically shows a magnification of principal portions of a radiation detector according to the second embodiment having a photodiode array according to the present invention.

[Fig. 24] Fig. 24 schematically shows conditions in which a semiconductor chip is suction-clamped by a collet, with Fig. 24(a) being a cross sectional view showing suction-clamping by a flat collet and Fig. 24(b) being a cross sectional view showing suction-clamping by a pyramid collet.

[Fig. 25] Fig. 25 is a perspective view showing a photodiode array of a conventional technique.

[Fig. 26] Fig. 26 is a cross sectional view of a line D-D in Fig. 25.

[Description of the Numerals]

1, 41 ··· photodiode array

3, 43··· n-type silicon substrate

4 ··· photodiode, 5 ··· p-type impurity diffused layer

6 ··· transparent resin film, 7 ··· n^+-type impurity region

8 ··· accumulation layer

31 ··· scintillator panel

45 ··· front surface side depression portion, 45a ··· bottom portion

50, 55 … radiation detector

[Document Title] Abstract

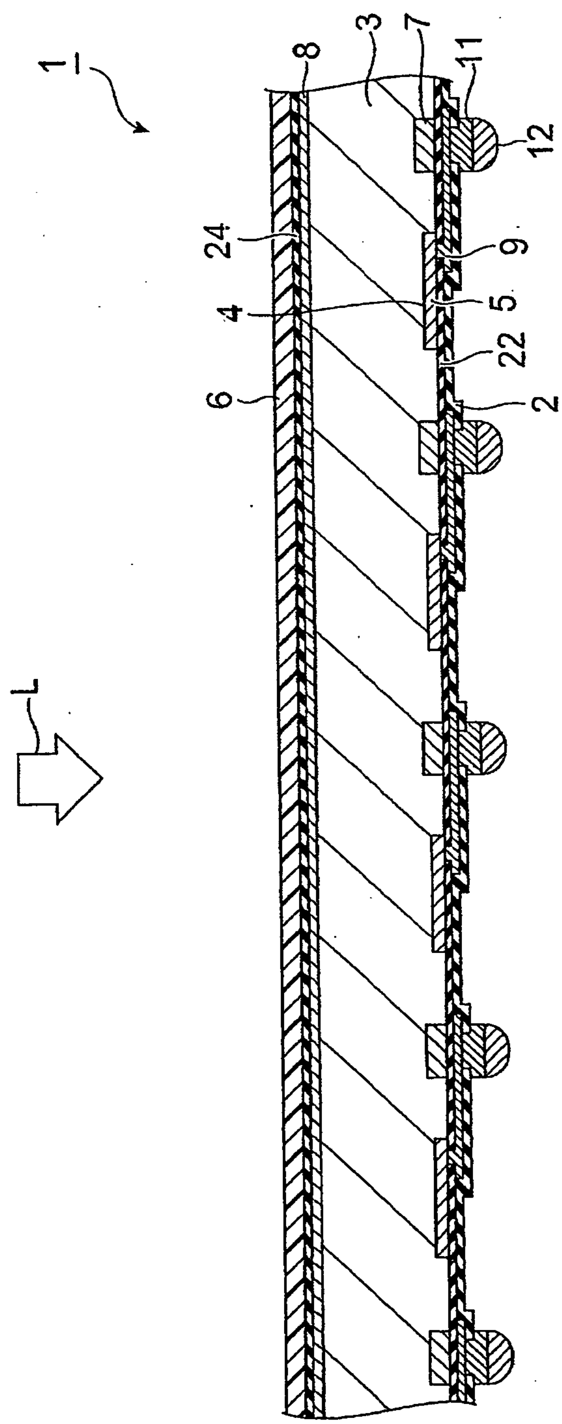
[Abstract]

[Problem] To prevent occurrences of noise due to damage of corresponding regions of photodiodes during mounting, in a photodiode array, a production method thereof, and a radiation detector.

[Means of Solution] A photodiode array 1 in which a plurality of photodiodes 4 are formed in an array on an opposite surface side to an incident surface of light L to be detected of an n-type silicon substrate 3, wherein, on the incident surface side, a transparent resin film 6 for transmitting the light L to be detected is provided so as to covers at least a region on the incident surface side corresponding to a region where the photodiodes 4 are formed.

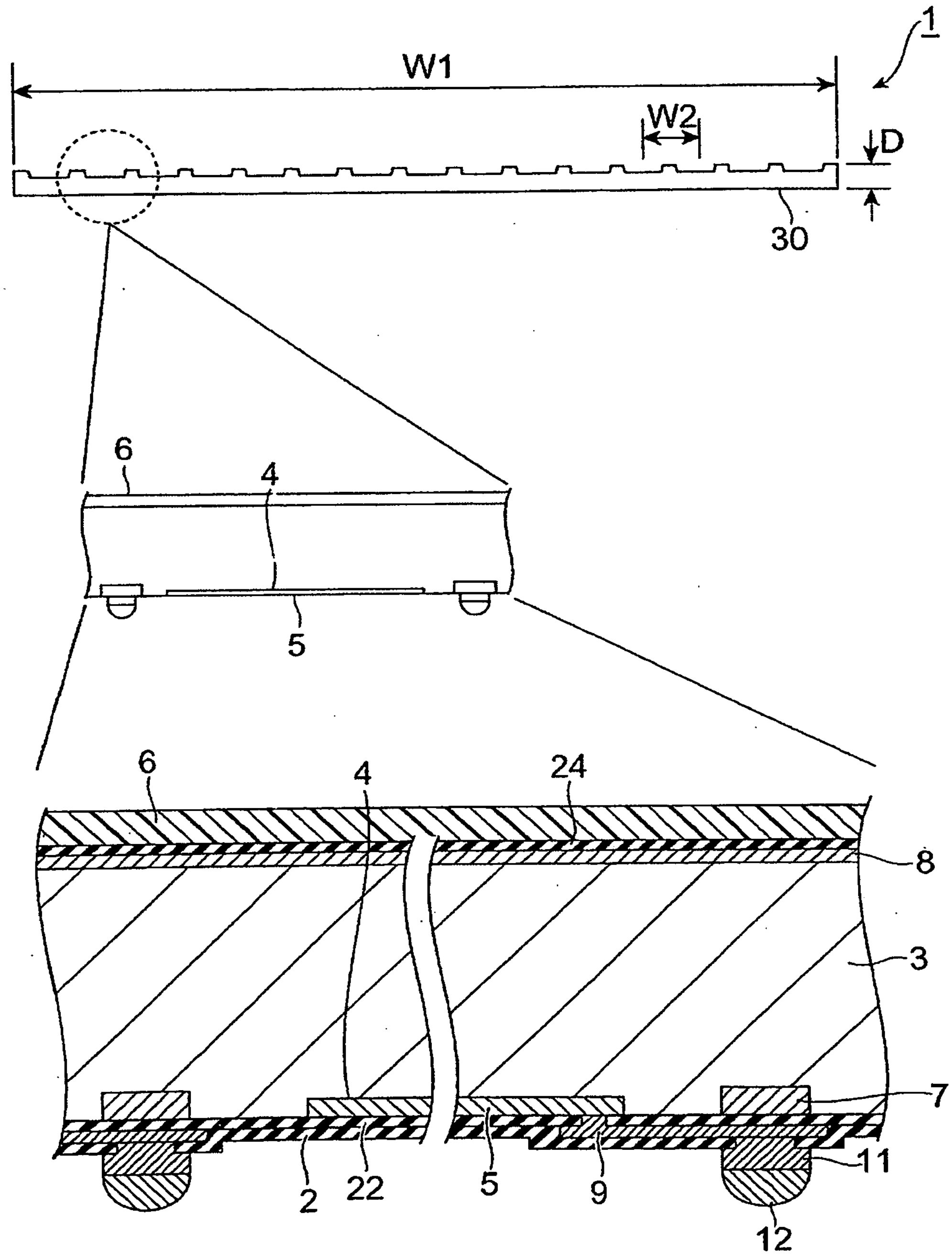
[Selected Drawing] Fig. 1

~~【書類名】~~　~~図面~~
[Document Name]　Drawings
~~【図１】~~
[Fig. 1]



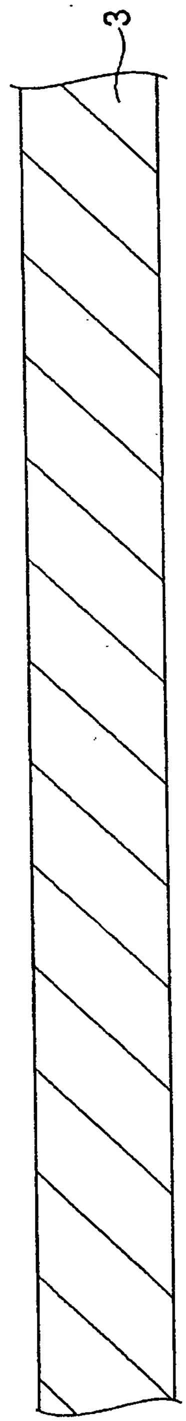
~~【図２】~~

[Fig. 2]



~~【図３】~~

[Fig.3]



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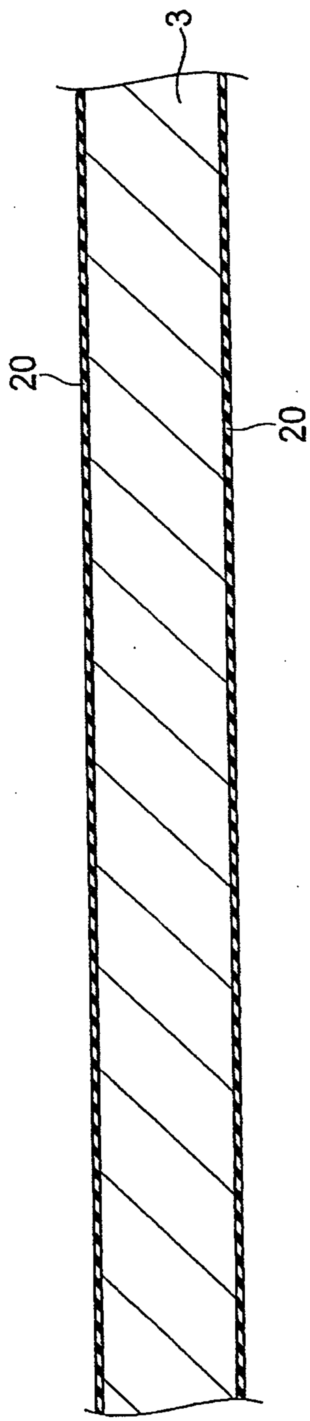
[Fig.4]



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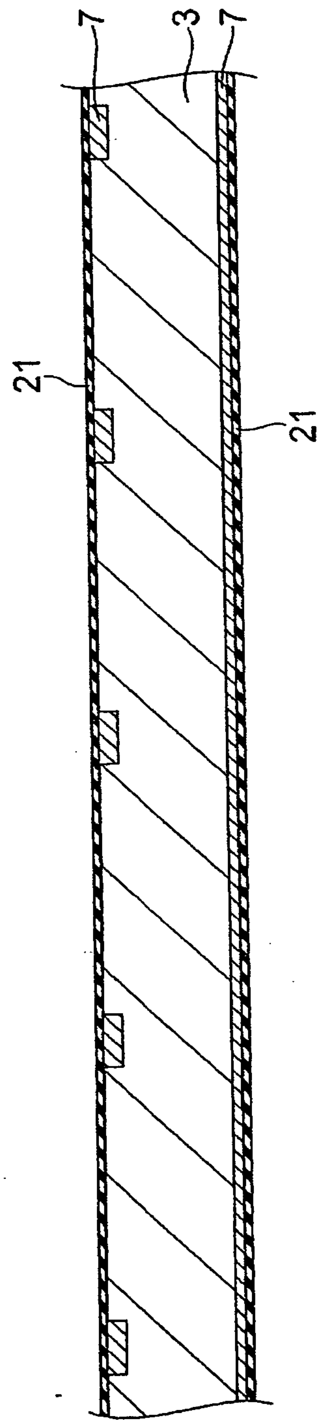
[Fig.5]



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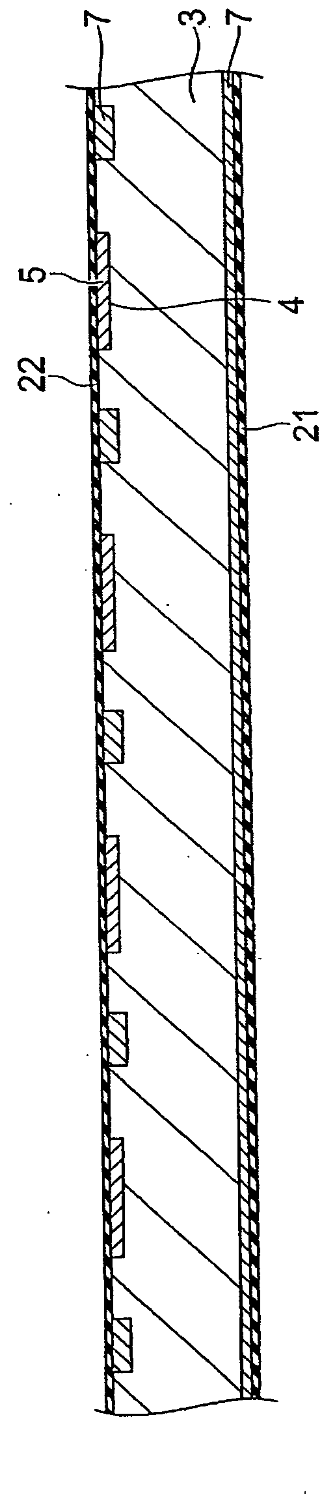
[Fig. 6]



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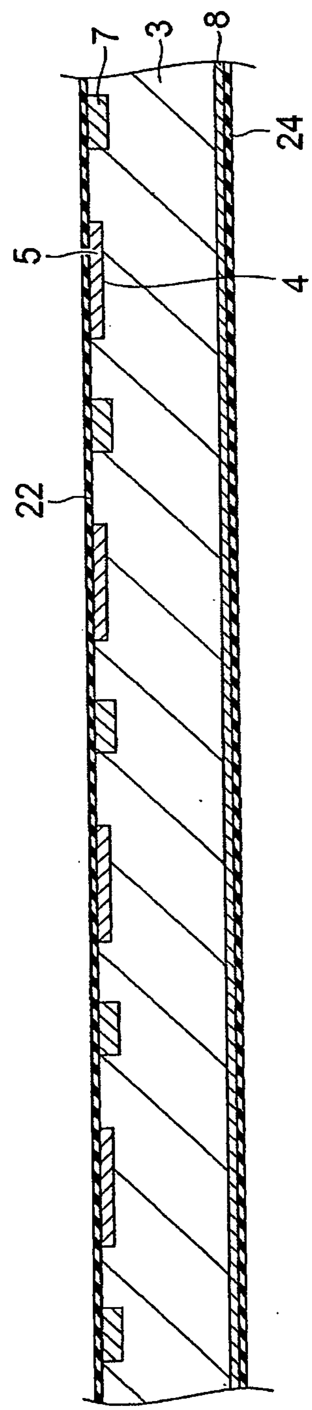
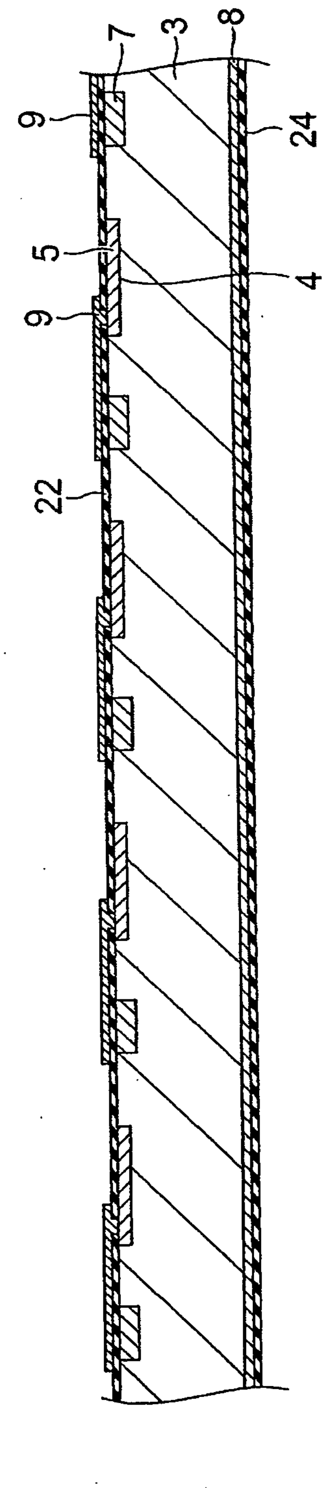
[Fig.7]

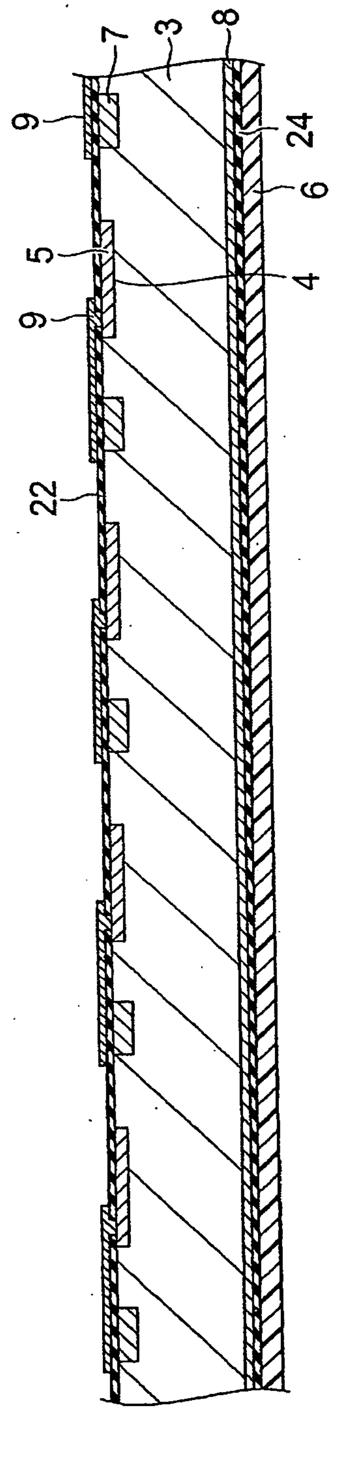


~~【図8】~~

[Fig. 8]

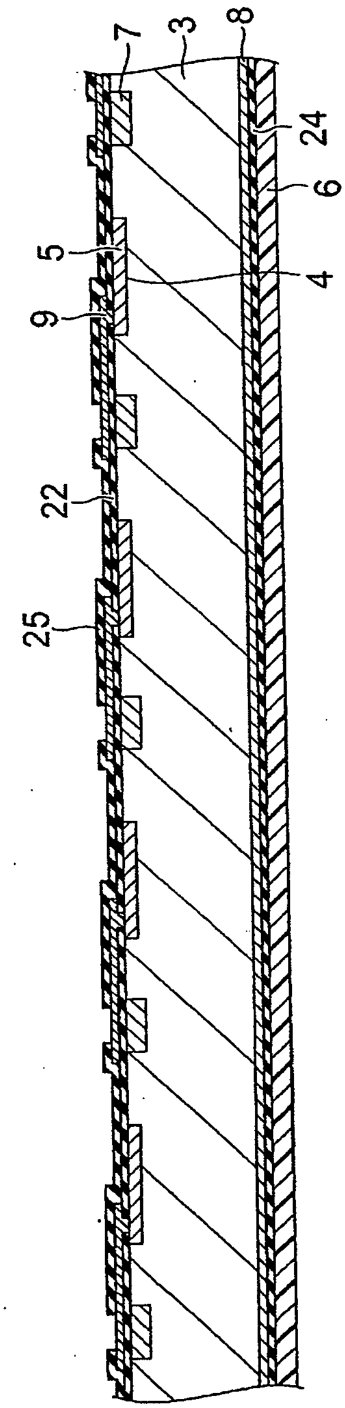


~~【図９】~~
[Fig. 9]



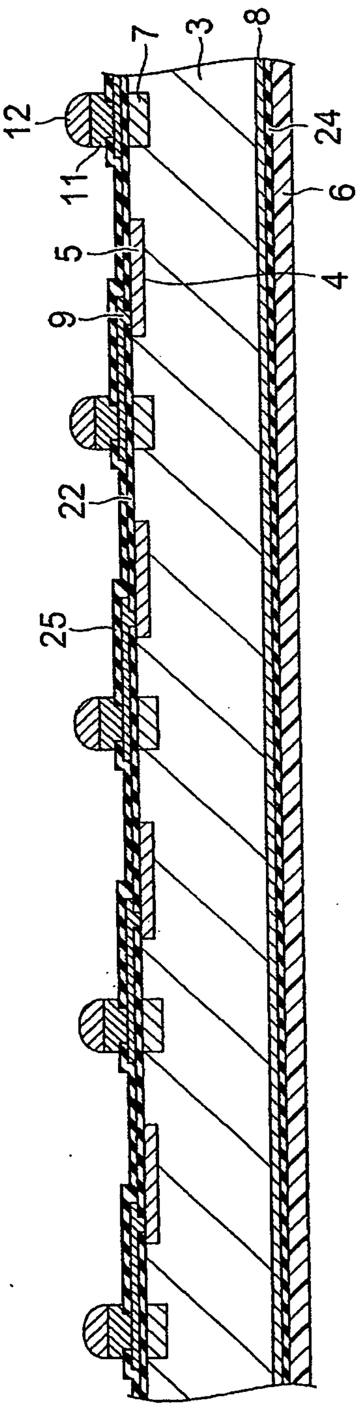
~~【図１０】~~

[Fig. 10]



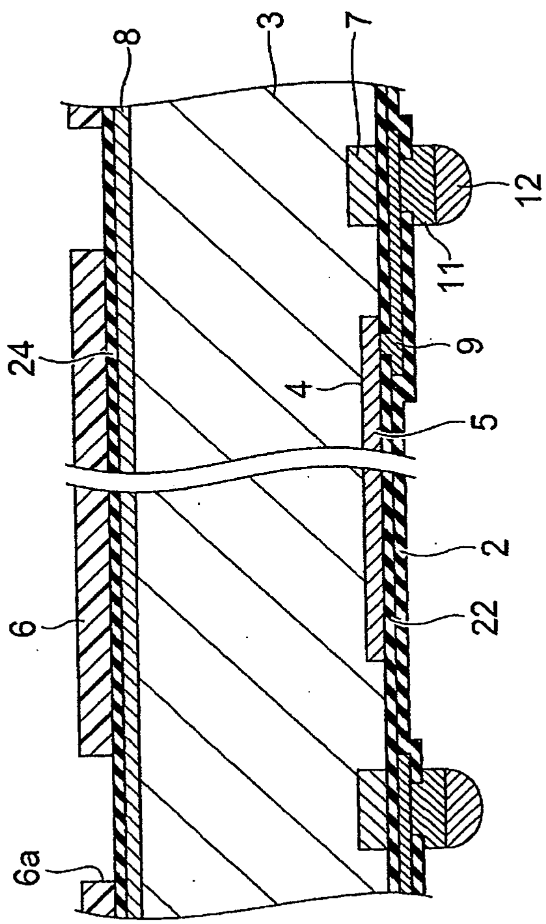
~~【図１１】~~

[Fig. 11]



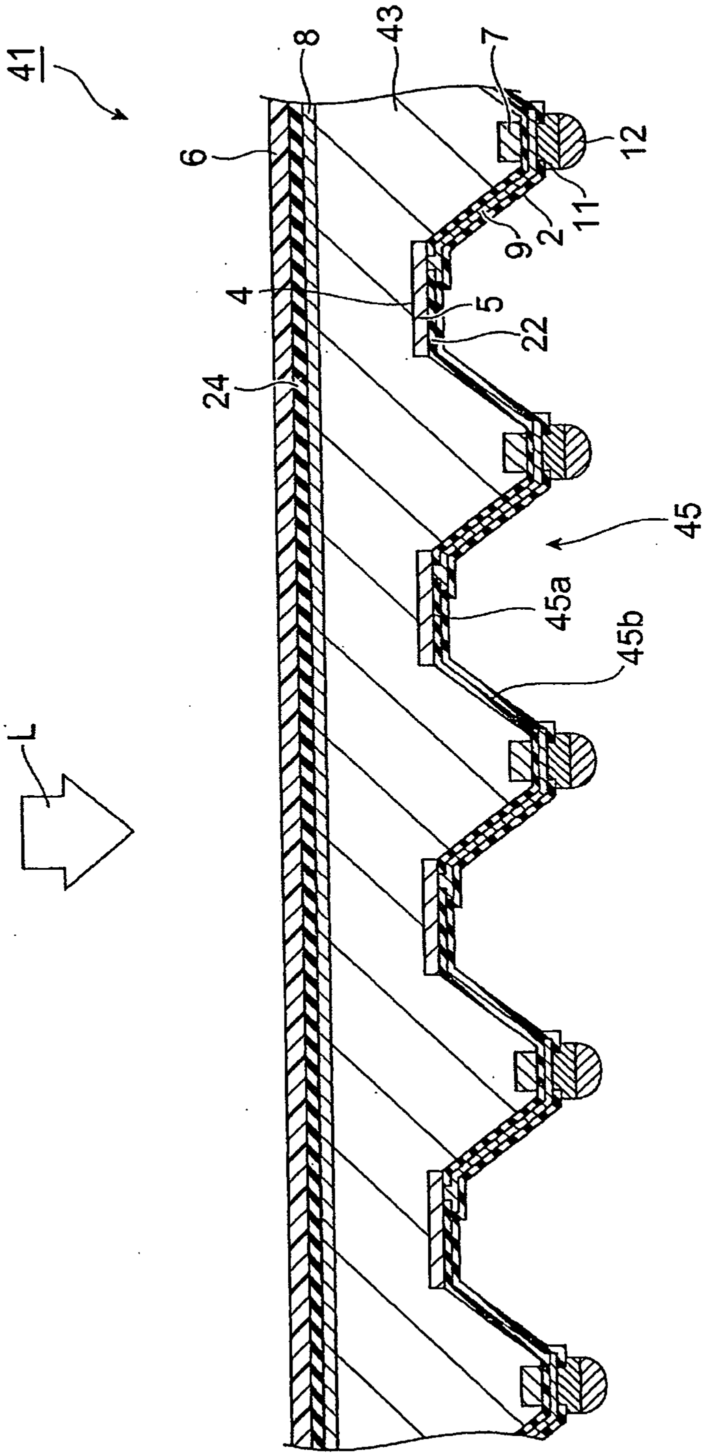
~~【図１２】~~

[Fig.12]

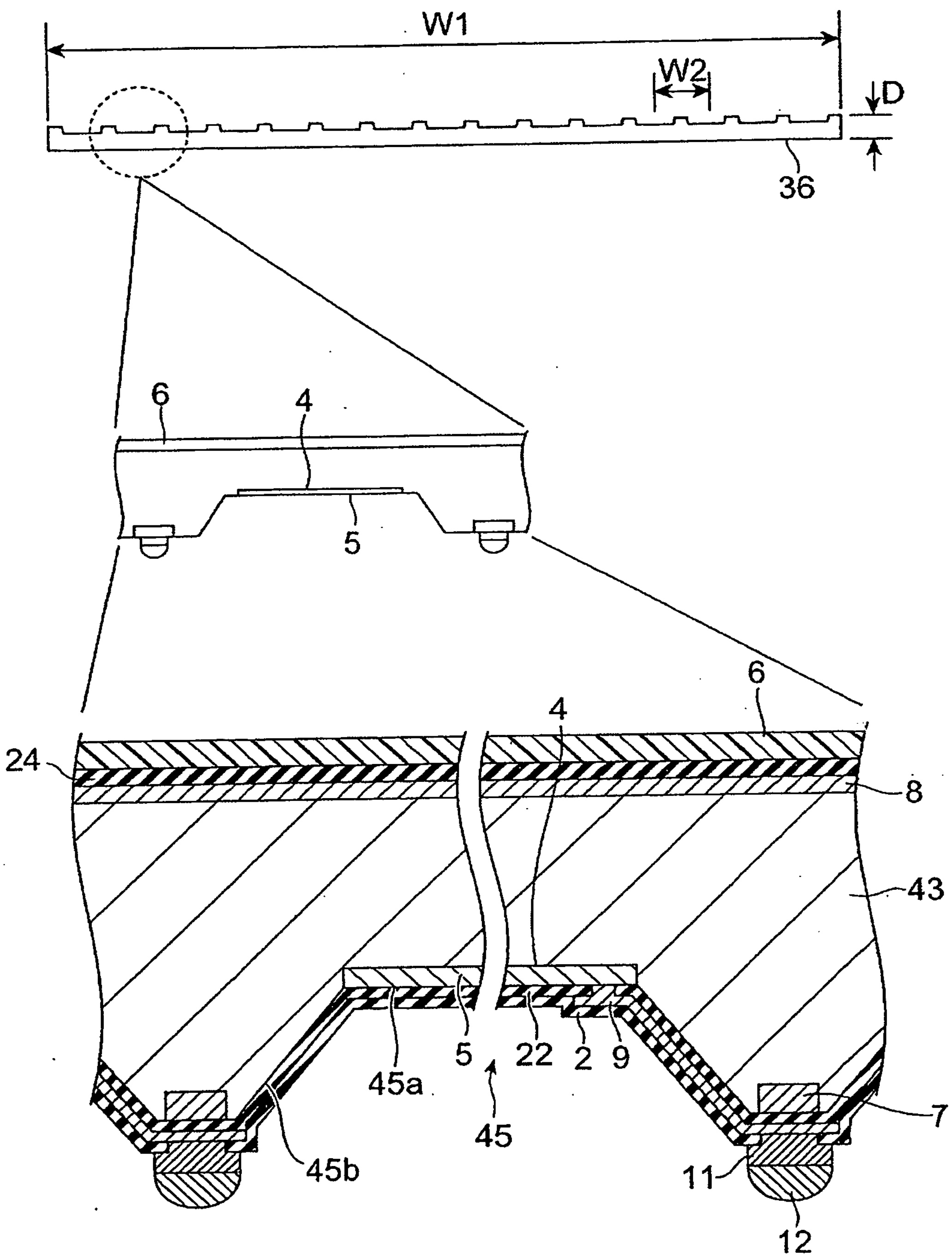


~~【図１３】~~

[Fig. 13]



~~【図１４】~~
[Fig. 14]



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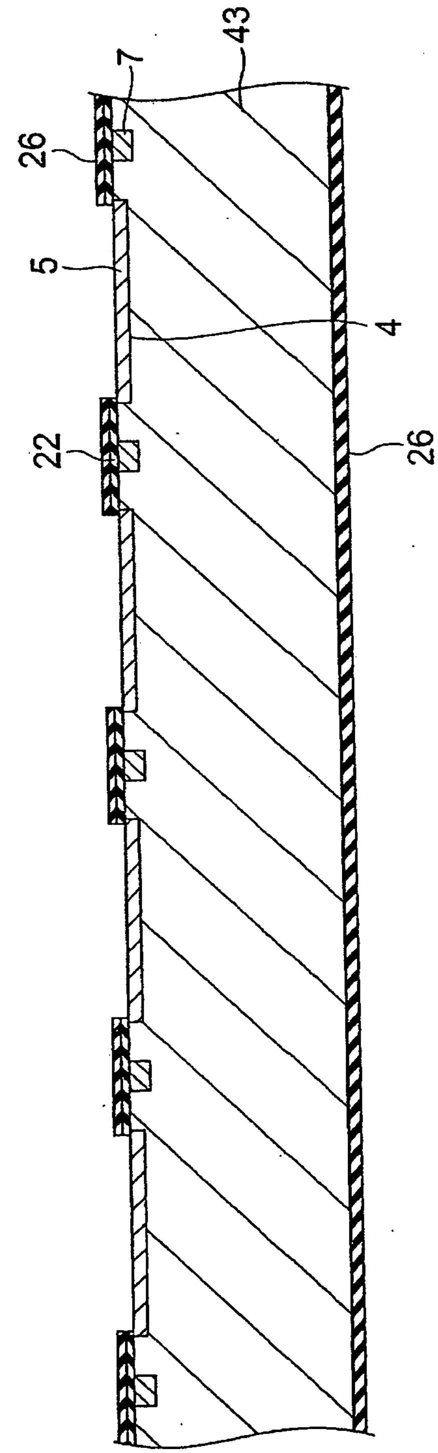
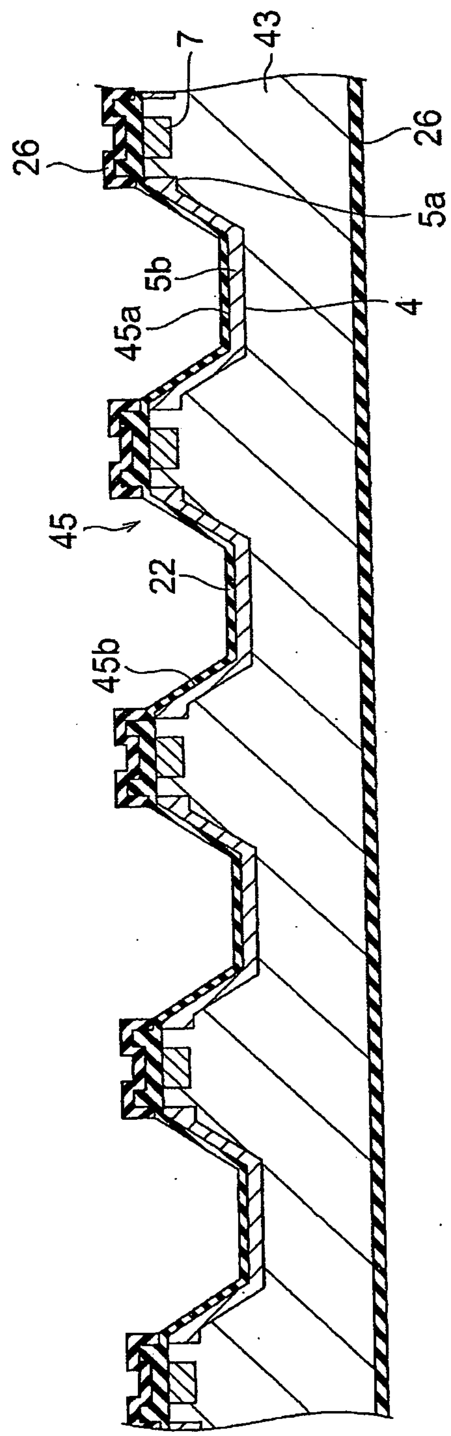
[Fig. 15]



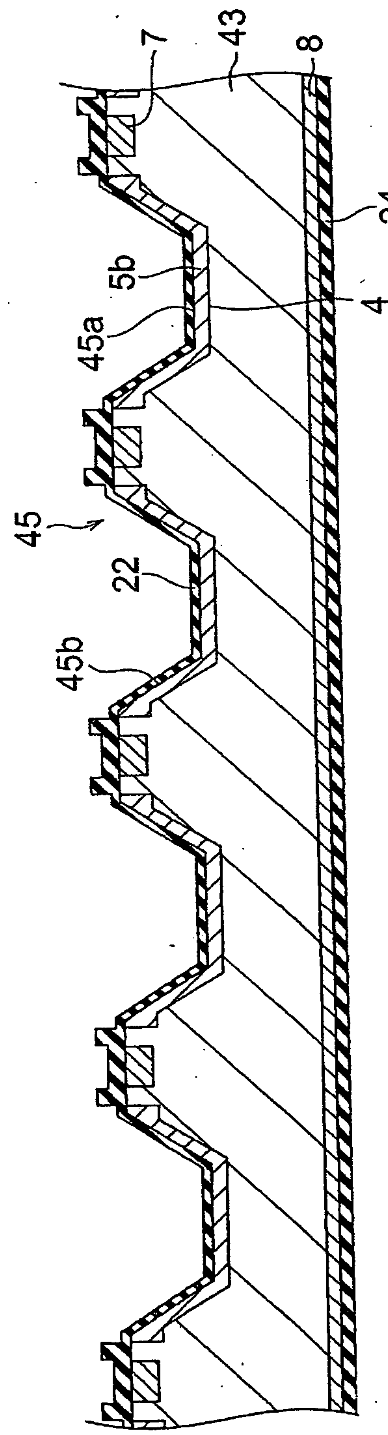
~~【図１６】~~

[Fig. 16]



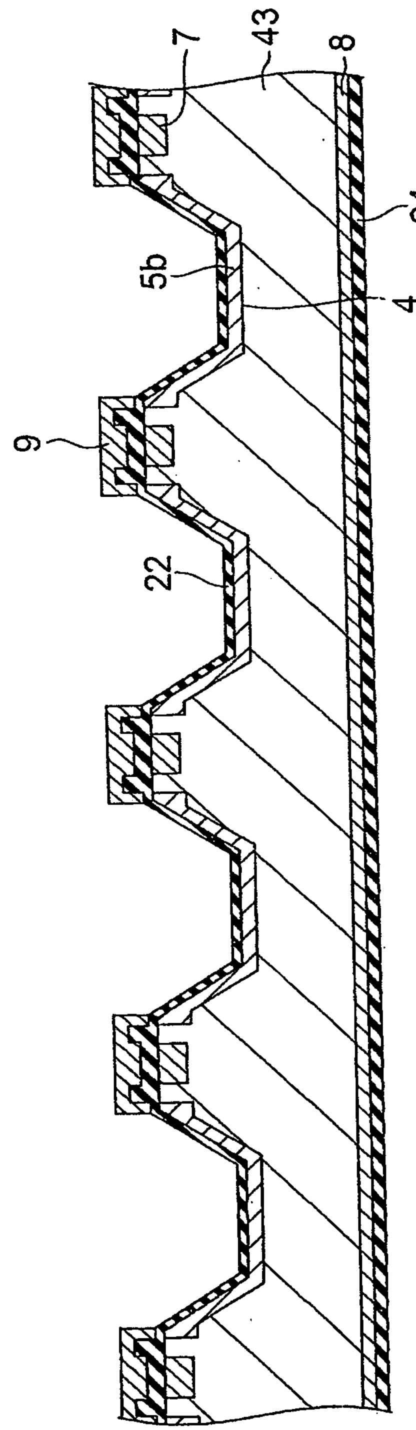
~~【図１７】~~

[Fig. 17]



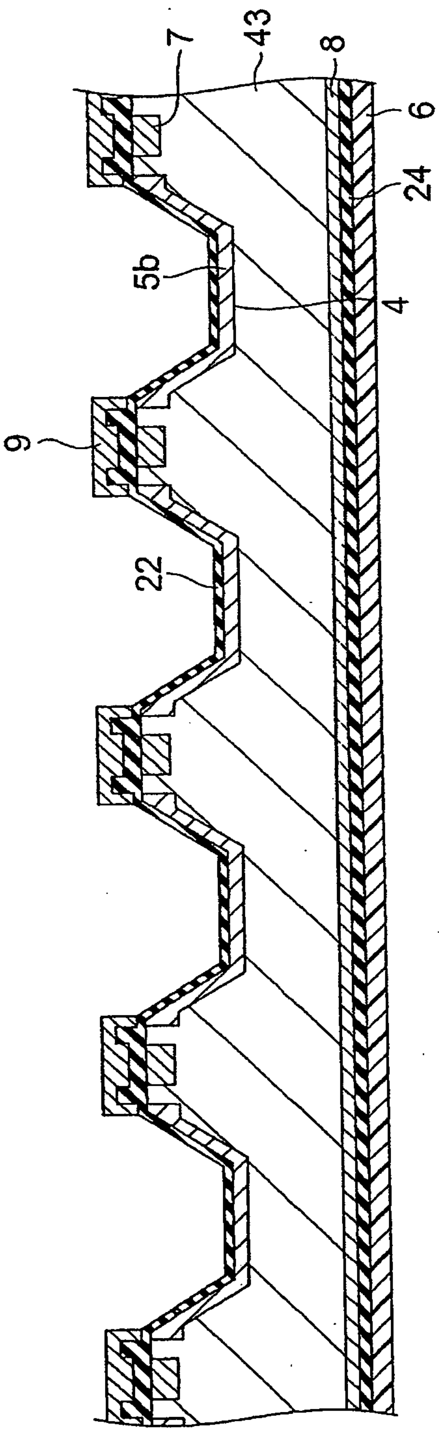
~~【図１８】~~

[Fig. 18]



~~【図１９】~~

[Fig. 19]



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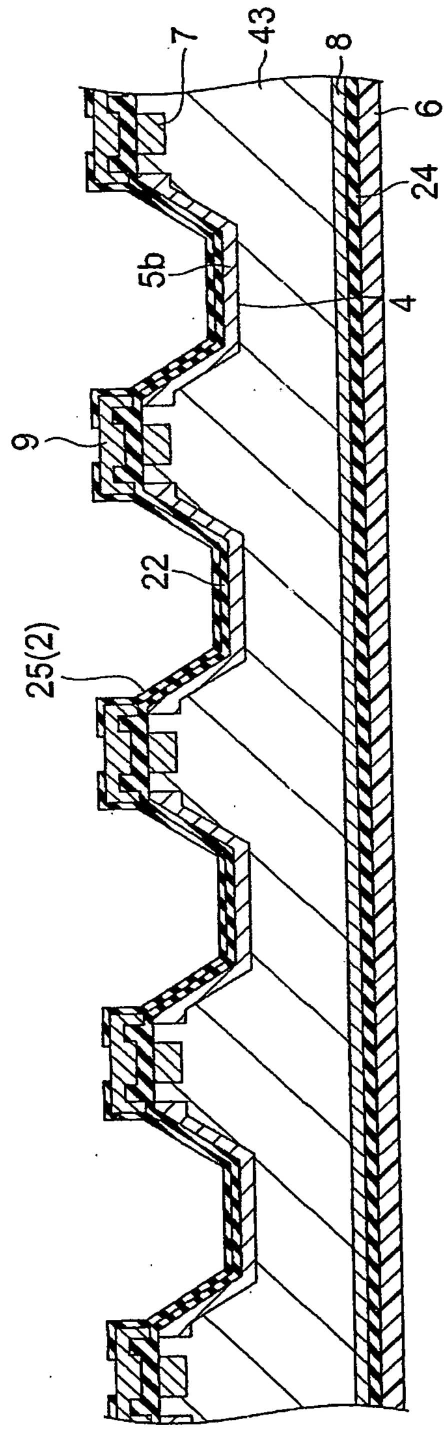
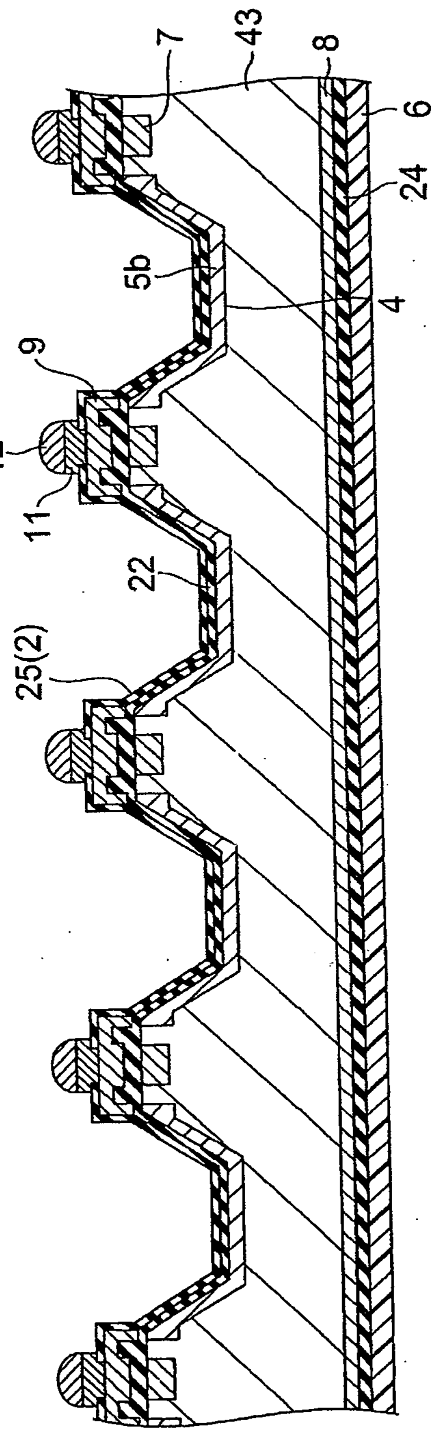
[Fig. 20]



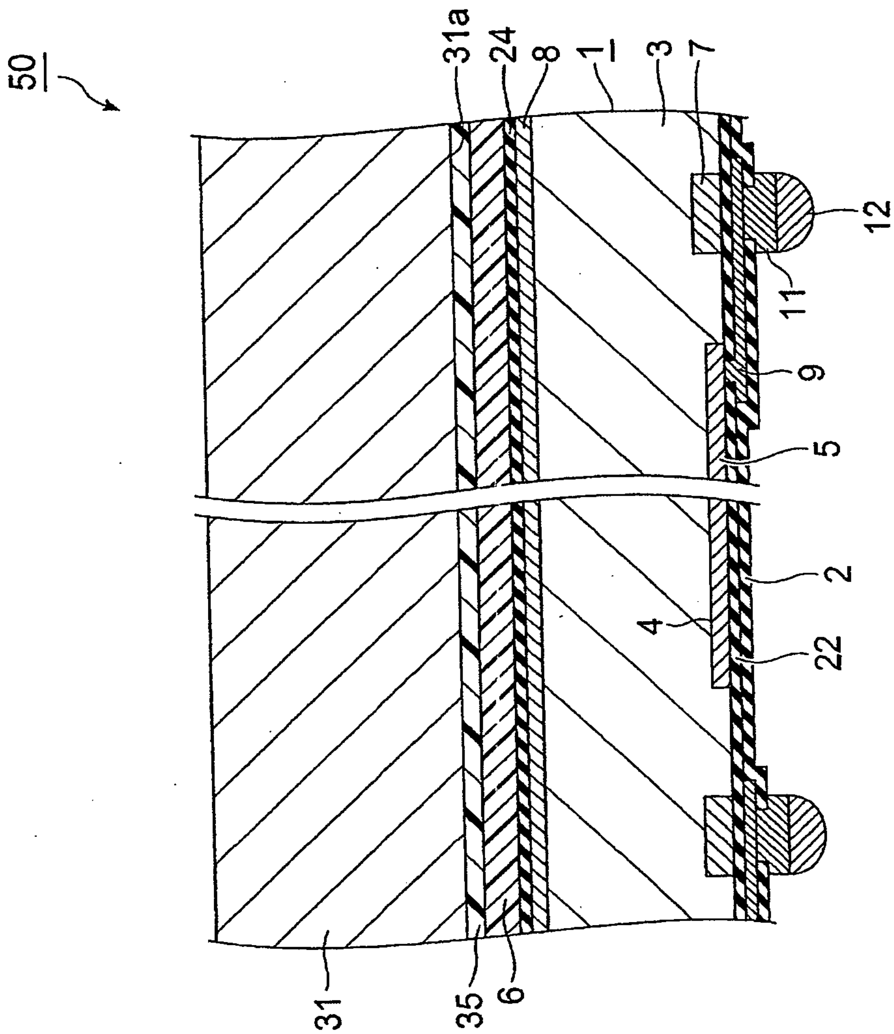
~~【図２１】~~

[Fig.21]



~~【図２２】~~

[Fig. 22]



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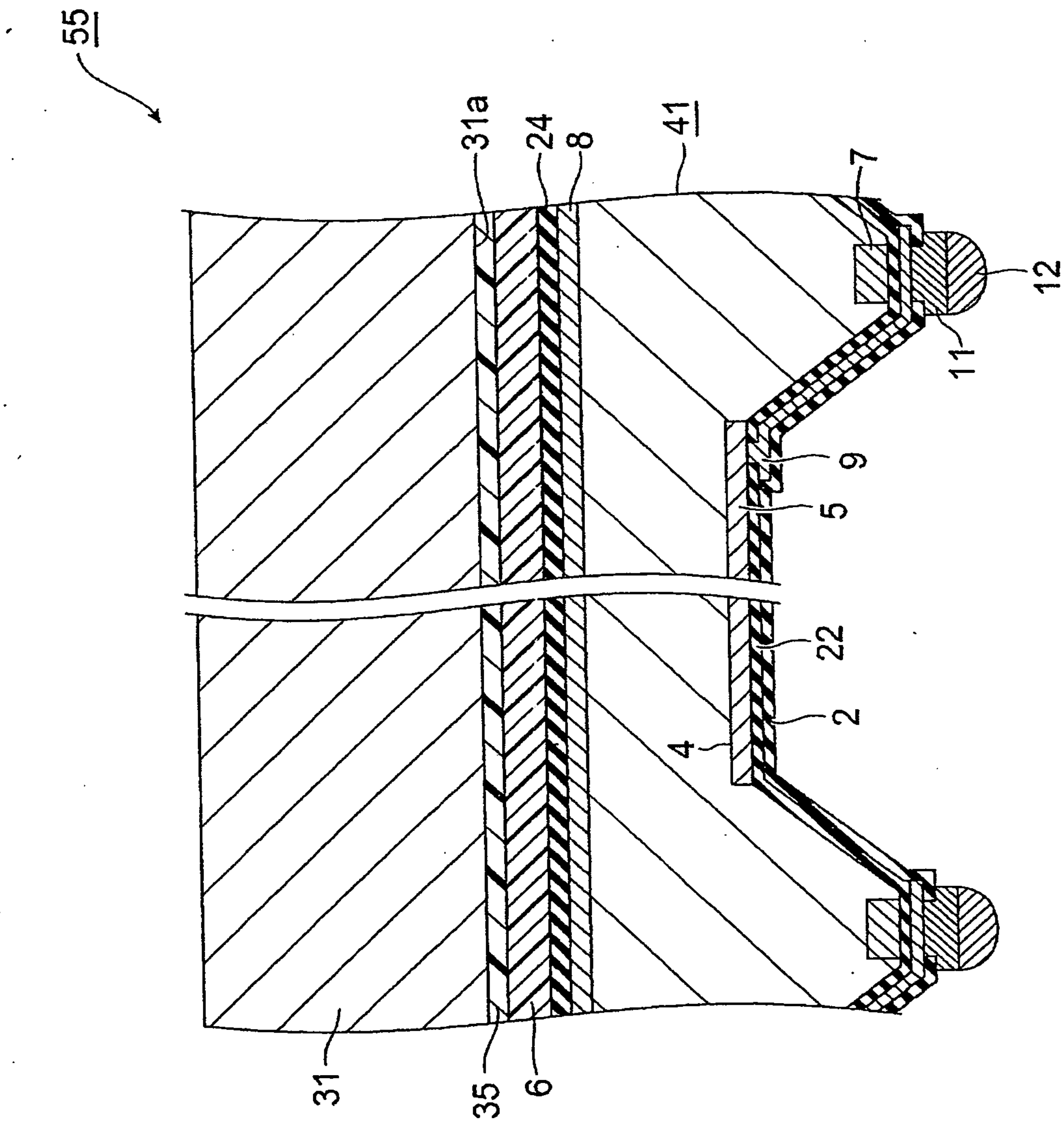
[Fig. 23]



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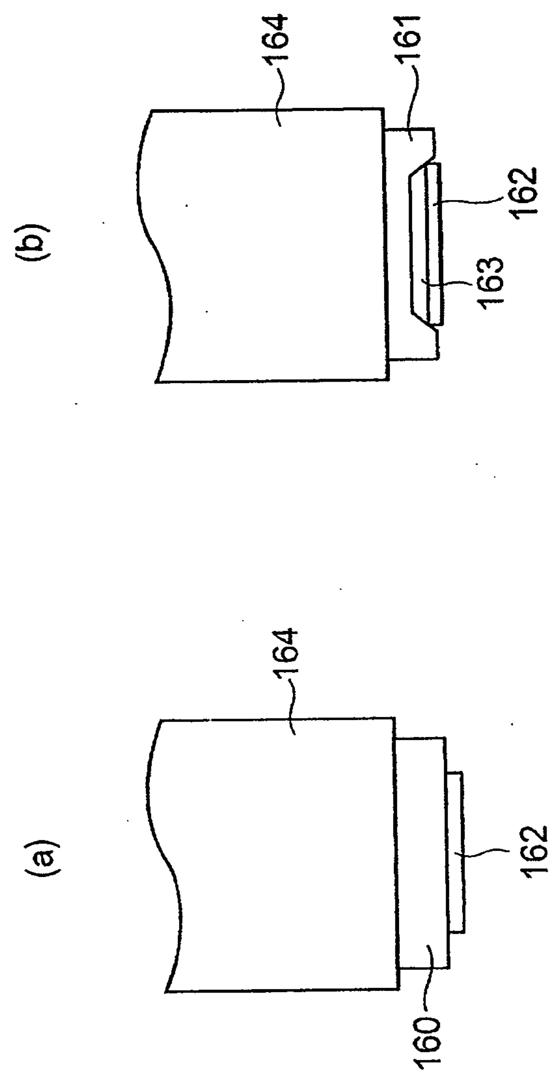
[Fig. 24]



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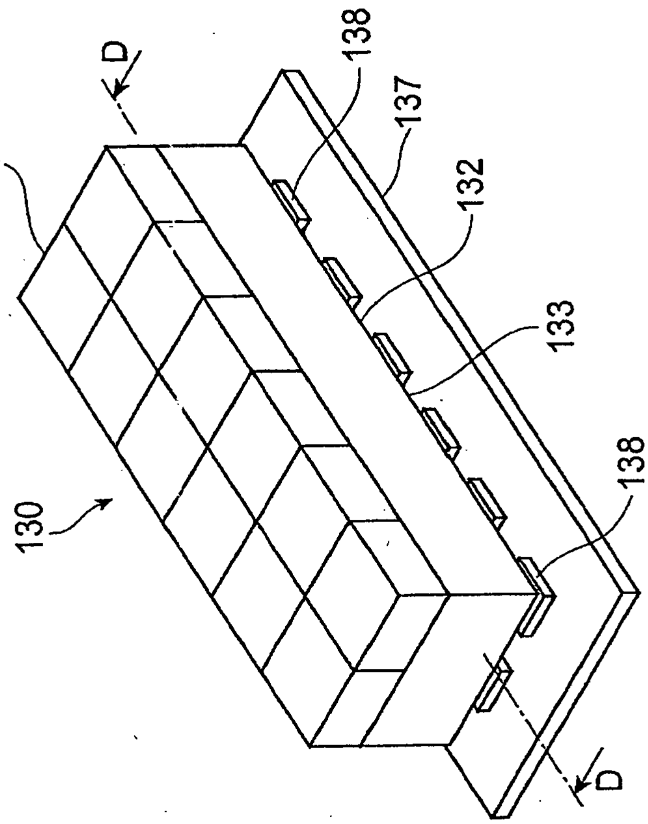
[Fig. 25]



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[Fig. 26]